ON ARTIFICIAL UNDERGROUND WATER

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From the most ancient times the clear and cool *spring* has been preferred to the tasteless water of the lake or river. A few decades ago people hardly knew what a spring was, they believed that it belonged to a mysterious underground vein which, from mere caprice, chose to come up to the surface, and the person that succeeded in getting water in a well had, by some peculiar chance, just hit on such a vein.

As long as it was only a question of procuring the small quantities of water, which were requisite for the modest hygienic wants of the past centuries, it was, as a rule, not difficult to find sufficiently rich underground veins. Even in considerably large towns each owner of a house had in his yard a well and close by the unavoidable latrine. Between these there was a close connection, the result of which is characterized by Liebig's well-known drastic saying, »that the urine of wells in towns was often considerably mixed up with ground-water«. At last this state of affairs could no longer be tolerated and, the opinion of the people becoming more and more enlightened, they began to demand, that the towns should be supplied with unpolluted and serviceable drinking-water. First of all they made use of such springs, the water of which

could be led by gravitation to the towns and there be distributed from the public fountains. Such an old water-work, partly renovated, has for the last 100 years existed at *Göteborg,* where the splendid water of Kallebäck-spring is distributed by a special system of pipes and fountains. Where they had no natural springs, they sought for underground veins. In respect to the quality, these old water-works were often excellent. But as, later on, people wished the water to be led into the houses and manufactories, the springs were no longer rich enough and many wells, sunk at random, proved such a failure that people no longer believed in using ground-water for larger towns.

A reaction now took place in favour of the hitherto despised lake-and river-water, the quantitative superiority of which had to cover the qualitative defects. Great and expensive works were erected for purifying and pumping up such water. At first they were satisfied to purify the water by precipitation, but it was soon found necessary to supplement this process by filtration through sand. As artificial filter-basins are very expensive, both to build and to work, *natural filtering,* if possible, was employed, which is based on the following principle.

Along the shore of a river, the bed of which consists of sand, a collecting-gallery is placed with an open bottom (see fig. 1), or a collecting-pipe with or without wells.

By pumping from the gallery its water-level sinks below the surface of the river, and this difference in the water-level causes the influx of the river-water through the sand-bed, which acts as a natural filter; the slime deposited on the surface of the sand being, according to

calculation, carried off by the stream. Any influx from the land-side was not taken into consideration in these first water-works.

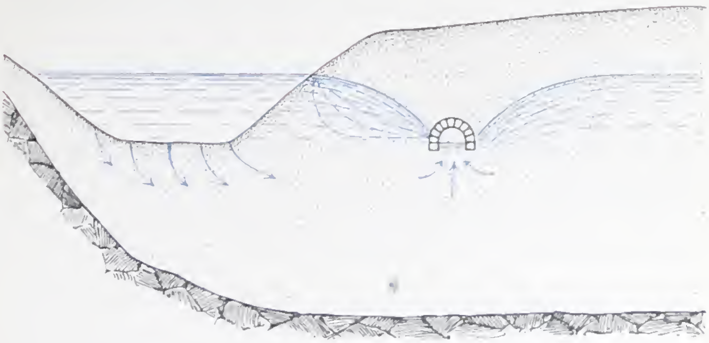

Fig. 1.

A number of such water-works have been constructed, but only very few have answered to expectation. Among these may be mentioned the entirely new water-works in the Bavarian town Schweinfurt on-the-Main, which river, at this spot, has an old weir built half across it. Above the weir there is a permanent stream of water from the Main into the shore, where it passes under the town and again flows into the river below the weir (Fig. 2).

At the examination made it was possible, in the observation-wells, clearly to follow the successive changes of the water from river-water to ground-water and the pumping experiments proved, that the capacity of the stream exceeded the needs of the town. The definite works consisted of wells, placed at a sufficient distance from the shore to enable them to give real ground-water. As the weir is several hundred years old, the capacity of the

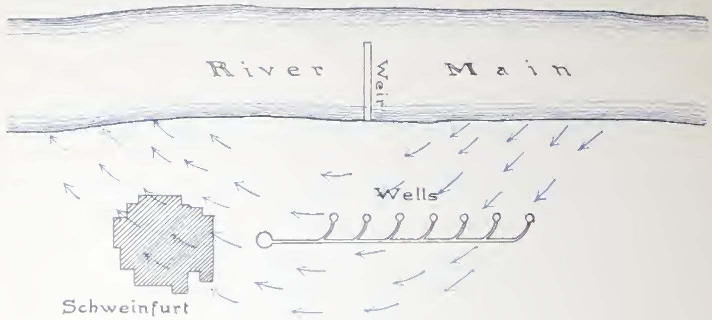

Fig. 2.

river to keep the bed clean can be considered as clearly proved, and there is no fear whatever of the ground-water falling off so long as the natural filter is not more strained than hitherto.

But the greater part of such works have, as before mentioned, been unsuccessful in consequence of the pores of the filter-bed getting gradually filled up by slime, which the current of the river has not been able to carry off. An example for this is the now abandoned »Emperor Francis water-work» in Vienna, built by the Emperor Francis I.

Toulouse has also unsuccessful water-works. Here, however, the cause was not of a quantitative, but of a qualitative nature. The collecting galleries, placed along the Garonne, of which the oldest is nearly 70 years old, have had to be lengthened in the course of time, but that was not because of the capacity having decreased, but because of the want of water having increased. (See Mandoul, Les eaux d'alimentation de la ville de Toulouse.)

At the present time all the galleries and wells together supply 20,000 cubic metres of water a day, of which about half is ground-water, while the other half consists of naturally filtered water from the Garonne. The natural speed of the current of the river is quite sufficient to tear off and carry away the particles of slime deposited at the bottom. The capacity of the filter-bed is thus retained undiminished; but unfortunately this capacity has been much too great from the beginning to be able to produce an effective purification of the river-water. Although the water coming from the land-side is ground-water of a perfectly good quality, the water in the pipes is rich in bacteria and other foul matter which, no doubt, come from the Garonne. In consequence of this annoying fact, it is said they are thinking of abandoning all the collecting pipes and of building ordinary artificial filter-basins for a future daily consumption af 35,000 cubic metres.

There are, however, several such works which, although quantitatively not answering to expectation, yet qualitatively have given a result of the greatest importance for the technical development of water-works. As a rule the capacity of the collecting-galleries has decreased while, at the same time, the quality of the water has improved: the temperature has become more constant and its chemical qualities have changed to such a degree, that it cannot possibly be attributed to its short underground course from the river. Although, from the beginning, no influx was expected from the land-side, it became, after each new installation, more and more evident that it is just from the land-side that the pipe receives its water, when the natural

filtering had ceased or decreased after the river-bed had become covered with slime. Some distinguished engineers, such as *Dupuy, Belgrand, Salbach, Thiem,* etc. now began to study the real nature of the underground water-veins, and the result of their investigations was a new science: *Hydrology* or the doctrine of the origin of ground-water, its movements and its quality. It is now a well-known fact, that *ground-water streams* are running under the surface of the earth, and their course can be followed, their direction and inclination determined and their capacity calculated with an accuracy, which excludes all risk of water-works, based thereon, being unsuccessful. During the last few decades ground-water-works have therefore been built with the best results for towns of hundreds of thousands of inhabitants. While hydrology has developed to an exact science, a great many carefully studied epidemics clearly proved, that infection can be spread by drinking-water, polluted by certain bacteria. Every possibility of the ground-water being infectious is generally excluded, whereas nearly every open water must be considered as suspicious. The highly developed art of filtration has, no doubt, succeeded in reducing the danger to a minimum, but it is nevertheless a well-known fact, that cholera or typhus bacteria can pass through the thin sand-bed of an ordinary filter-basin and the very best filtering plant, therefore, does not give the same absolute protection against epidemics as a rationally built ground-water-work. *Ozonising* is certainly an effective means of completely destroying all impurities in the water, but the method is expensive and is, as yet, in an experimental stage; besides, even

if river-water can be rendered sterile, there still remains the great drawback of its high summer temperature when compared with the refreshing coolness of ground-water. First after being filtered, ozonised and cooled, can river-water be compared with ground-water; but such a complete treatment is, from an economical point of view, out of the question, at least in the immediate future.

The hygienic, economical, and esthetic advantages of ground-water are nowadays so well known, that every town, intending to build water-works, should first of all try to fill its wants from visible or underground springs. Water, running on the surface, should be made use of only when careful hydrological investigations have shown, that ground-water cannot be obtained at a reasonable cost. The capacity of a ground-water stream is dependent on two factors: *the extent of the infiltration-area and the geological nature of the underground.* A considerable stream requires first of all an extensive territory with a porous surface, which absorbs and lets rain-water go through, and further a sufficiently thick and porous layer of sand or rock. If the infiltration-ground is too small, then not even the deepest and most porous gravel can give a sufficient quantity of water; and if the ground consists of fine or clayey sand, no real stream can go through, but it will get filled to the surface and the filtration-capacity will almost entirely cease, however porous it otherwise may be.

In the Scandinavian countries the ground-water prospects are generally so unfavourable, that it is often impossible to satisfy the wants of a town of a few thousand inhabitants. The cause of this is the peculiar geological

formation of these countries. Broad and level river-valleys, filled with powerful layers of sand, do not exist. Where the rock does not appear at the surface, it is often hidden by clay or by hard compressed, almost impermeable moraine-gravel. During the glacial period, when even our highest mountain-tops were buried under glaciers, all the sand-beds from older periods were torn up and carried away, being finally deposited in the Baltic, or on the plains of Northern Germany. After the melting of the ice a great portion of the land sank, on two different occasions, below the surface of the sea, and each such submergence and the succeeding upheaval carried with it the rinsings and assortment of the moraine-masses, as sand or clay, of which the latter appears partly on the surface and partly deposited between older and younger layers of sand. There are districts, containing thousands of square kilometres, where the surface consists of nothing but rock, moraine-beds or clay; where therefore but a very small portion of the rain-water can find its way into the ground. If all deeper layers of sand are wanting, then the ground-water question must irremediably be abandoned.

But it may happen that, although the filtration-territory is not sufficiently large and the supply of ground-water small, yet the underground condition is in itself favorable. In many a valley there is under the clay-cover a layer of sand or perhaps even of coarse gravel. The result of the hydrological examination is negative in respect to the ground-water-supply being insufficient in consequence of deficient infiltration but, at the same time, it has been proved that the underground current could, under favorable

conditions of infiltration, have yielded a far richer ground-water-stream. In such a case it should not be given up, but reasoned out thus: As it is only the infiltration-quantity which is insufficient, the engineer must assist nature with *artificial infiltration.*

If, for instance, the underground filter-bed comes to the surface to the extent of but one hectare, an *annual* quantity of rain-water of, at most, 3,000 cubic metres will be infiltered there, whereas the surface of the sand could, without the least difficulty, *daily* pass at least an equal quantity. If the ground can as easily pass, in a horizontal direction, a constant stream of the same capacity, the problem would be easily solved by daily leading from the nearest river 3,000 cubic metres of water over the sandy surface in question to be infiltered there and changed to ground-water.

The principle is old, but has hitherto only been applied on a very small scale and under rather unfavorable conditions. At *Wiesbaden* and *Remscheid* they have led the water of brooks into open infiltration-ditches. At *Chemnitz* the water from the dirty river Zwonitz is led partly to a filter-canal, the bottom of which goes down into a layer of gravel, and partly to a grassy field which, at certain intervals, is watered according to the well-known *irrigation system* for the purification of sewerage-water. During winter, when irrigation is impossible, only the filter-canal is used. Unfortunately the gravel-layer is much too thin to be able, in a horizontal direction, to pass any large quantity of water, and infiltration must therefore take place quite close to the wells, from which the water is pumped before it

has had time to get changed and improved to the desirable degree.

In the year 1888 *Baurath Thiem* came forward with a project for water-works for the town of *Stralsund*, based on real ground-water production. From a neighbouring lake 3,000 cubic metres of water were daily, by gravitation, to be led out over 5 irrigation-basins of together 3.6 hectares in extent, and only during winter, when this sort of work was impossible, continual filtration was to take place in an infiltration-basin. Here, however, the layer of sand was also insufficiently deep to yield a collected stream, and the water had to be pumped from wells close to the basins. The project fell through, for the cautious fathers of the town feared that »the water would run off into the sand«.

Thiem has again taken up the idea to produce artificial ground-water, but no longer by irrigation but instead by the help of the old method: natural filtering through the river-bed. *Thiem* considers — and no doubt he is right — that the reason, why so many establishments, based on this principle, proved failures, was the deficient examination of the speed of the current and the admissible infiltration-speed. These two stand in a certain relation to each other: the latter increases with the former. As long as the filtration-speed is not increased above a certain limit, the speed of the current is sufficient to prevent the slime to run into the sand, the pores of which are thus kept open: otherwise the filter must, sooner or later, become stopped. Only after long pumping-experiments and careful observations of the quantity of ground-water can a correct

idea be formed concerning the permanent filtration-capacity of the river-bed. But of quite as much importance for *Thiem* is the qualitative side of the matter i. e. the capacity of the natural filter to give a ground-water perfectly free from bacteria and of a constant temperature. Such a thorough change is, of course, not suddenly obtained by infiltering the river-water, nor even by a few days continued filtering; it requires a certain time i. e. a certain minimum distance from the shore and the collecting pipe or wells. The longer the distance, the more complete is the purification, but also so much the deeper must the surface of the water be sunk to get the necessary speed for filtering. To solve all these important questions much more extensive examinations are requisite than for determining the capacity of a natural ground-water stream. As far as I am aware, no other water-works have been planned in this way and carried out than the new water-works at *Essen on the Ruhr*, the building of which has been led by *Thiem* personally, and of which one can therefore expect the best results.

In *Sweden*, where the unfavorable conditions of natural infiltration, more than elsewhere, necessitate the artificial increase of the ground-water streams, the irrigation-method is less suitable than in countries with a milder climate, although it can, of course, with advantage be used during those seasons, when the ground is not frozen. The usual method, what is called the natural filtration through the river-bed, can only rarely be made use of (see page 17), for our rivers flow, as a rule, through rocks, moraine-gravel, or clay. The most suitable for our country is *the cleansable infiltration-basin*, i. e. a basin built in the porous

ground with sufficient depth of water to prevent the freezing of the sand and with sufficient surface to limit the number of cleanings to a few per year. The principle is explained by the annexed sketch of the scheme.

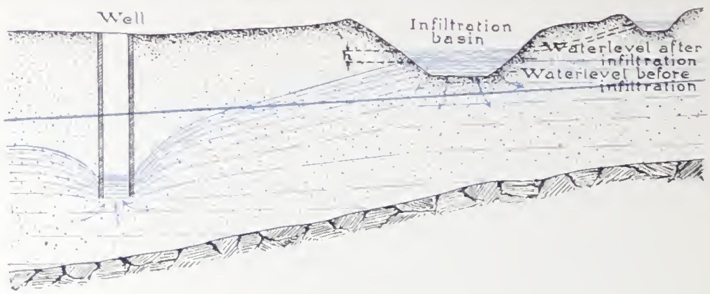

Fig. 3.

The bottom of the basin is placed, if possible, above the natural ground-water level and is covered with a layer of fine and uniform filter-sand. The surface-water which is first led in, goes freely through the bottom, but soon enough the increase of the ground-water produces a rise of its level and continual filtering begins. In consequence of the ever increasing deposit of slime the infiltration-resistance becomes every day greater and the level of the water in the basin rises in proportion to the level of the surrounding ground-water. When this difference in height — h in the sketch — has reached a certain maximum, say one metre, then it is time to clean the basin: the influx is stopped, and the level of the ground-water sinks below the surface of the sand, which is cleaned exactly as in a usual artificial filter, after which the water is admitted and the basin again operates. During the short time this

process demands, the diminished quantity of ground-water is replaced by the water accumulated between the basin and the well. If the infiltration is divided among several basins, one of them can be cleaned while the others continue to operate.

An infiltration-basin, constructed and managed in this way, should retain its undiminished capacity for many decades. There are examples of artificial filter-basins which, under the most unfavorable circumstances, have been working 30—40 years with great speed of filtering and irregular care, without having ever been aired or received any other repairs than the usual scraping. An infiltration-basin, built in suitable ground, which works with a uniform and low rate of filtration and is always cleaned in good time, is as little exposed to getting filled up with slime as a usual modern filter is, and can just as easily be provided with a new sand-bed of the usual depth by digging up the bottom.

The doubts, often expressed with regard to it, seem to me as little justified as the fears at *Stralsund* that the water would »run off in the sand». For if more surface-water is infiltrated than is used afterwards as ground-water, then the water-level below the wells, in the direction of the stream, must also be raised; when on the contrary, the wells give more water than is infiltrated, the capacity of the ground-water stream is diminished as also its depth, and the surface sinks below the wells. An unchanged ground-water level proves that the infiltration and consumption completely coincide with each other. By daily observ-

ing the height of the water below the wells one can follow the course of infiltration and regulate it at will.

The principal condition for a good result is to find the right distance between the basin and the well. The mechanical purification of the water and the excluding of the bacteria takes place during infiltration and in the upper layer of sand; but for the equalizing of the temperature and the chemical changes, a certain time is required i. e. a certain distance between the basin and the well (see page 13) and the longer the distance is which the water has to go through, the greater and more valuable becomes the underground reservoir, which can be made use of when the basin is to be cleaned, or when an occasional increase of water has to be pumped up. But on the other hand it is of the greatest importance that the inclination of the surface of the water, between the basin and the well, be sufficient to overcome the resistance in the pores. If the difference in height is limited, it is important not to make the distance too great, for if the inclination be insufficient, the natural filter-bed cannot give passage to the desired quantity. To determine the right inclination purely theoretically is hardly possible, and the only correct method of ascertaining this is an experiment on as large a scale as possible with a basin dug out for the purpose.

Thus we see that the artificial increasing of groundwater is often combined with considerable difficulties, and that it is impossible, without a previous examination, to calculate beforehand the quantitative and the qualitative results. In some cases the geological formations are so favorable that even the largest towns can in this manner

be supplied with ground-water of an excellent quality; in other cases, such as at *Chemnitz* and *Stralsund* the idea had to be given up of completely purifying the water, and even then the quantity received was very small.

Several Swedish towns will probably, in the immediate future, be supplied with artificial ground-water. For the town of *Luleå* a plan has been made which is based on natural filtration. The water is collected in wells near the bank of the River Lule, which here forms a wide enlargement with a gently sloping sand-bottom. There is, therefore, no current in the river, but the natural filtering-surface is cleansed by every wind, when the waves tear up the sand and carry off the slime. If this calculation should prove false, an infiltration-basin will be constructed on the land-side of the complex of wells, and the water will be led to it from the river.

The same principle will probably be applied at *Jönköping,* where the water will be taken from wells on the shore of the Vettern. It is a well-known fact that, during every storm, the water becomes turbid as far out as several hundred metres from the shore by sand torn up from the bottom, and thus the problem of preserving the permanent capacity of a natural filter is solved in the very best way.

The town of *Uddevalla* is supplied by gravitation from springs, the capacity of which is far from sufficient. The rain-water district consists of a broken mountainous landscape and is sufficiently large to yield the annual quantity of water, which the town will in future require. To be

able to collect and use all this quantity, the arrangement shown in Fig. 4 is proposed.

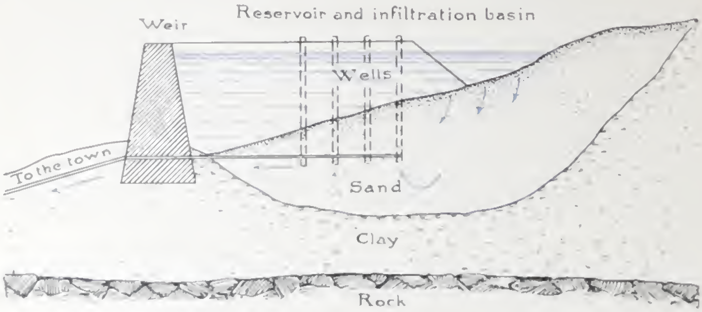

Fig. 4.

Above the weir an infiltration-basin is formed of sufficient size to equalize the influx and efflux variations and situated high enough to be made use of as a service reservoir. The water of the brook is led through a precipitation-basin, which is intended to free the infiltration-basin from the slime, then sinks down through the porous-sand-bottom and passes to the wells, which are accessible from a bank built across the basin. The strip of shore, situated between high-water and low-water, is large enough to need cleansing but once a year, during which process a broad bottom-strip is scraped away under the surface of the water. Any real ground-water production does not take place, although the purification of the water and the change of temperature will, no doubt, be complete in consequence of the considerable depth and extent of the basin and the sand-bed.

In the towns of *Gefle*, *Falun*, *Borås*, *Kalmar*, and *Hel-*

singborg ground-water streams are made use of, the capacity of which will, sooner or later, have to be increased artificially, and at *Göteborg* an establishment has been at work for the last 18 months, the principal arrangements of which deserve to be described.

Göteborg is situated on the Göta Elf, a few kilometres above its outlet into the Kattegatt. The valley is formed by strongly marked mountain ranges, and the bed of the river consists of blue clay. Single sand-hills rising above the ground indicate, however, that the clay rests on sand, and in 1890, by the advice of *Salbach*, a complete hydrological investigation of both this and the neighbouring valleys was made, and the existence of an artesian ground-water stream under the clay of the Göta Elf was established (Figs 5—6).

A calculation of the quantity was not made, for as the ground-water contained as much as 200 litre-milligram chlorine and 4 lmg ammonia, it was considered unfit for drinking-water both by Salbach and other experts. Two ordinary filter-basins were built for the purification of the water from the river and in the plan for enlargement, 4 new basins with a daily capacity of 11,500 cubic metres were included.

In the year 1895, however, the ground-water question was again investigated. The opinions about the quality of good water for water-works had now undergone a considerable change, and they were no longer afraid of chlorine and ammonia in such a ground-water. Renewed investigations, however, gave the result, that the natural ground-

BASSIN DU GÖTA ELF

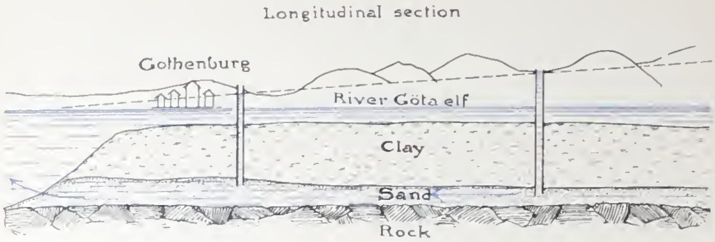

Fig. 5.

BASSIN DU GÖTA ELF

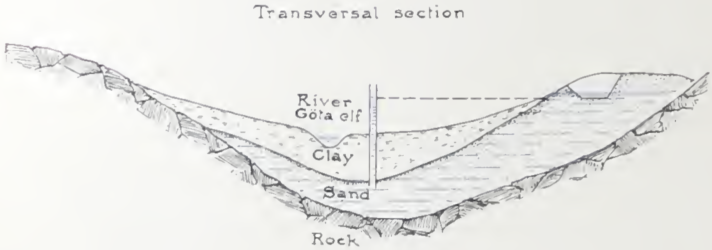

Fig. 6.

water supply is only 2,000 cubic metres in 24 hours, an insignificant fraction of the quantity required.

Instead of now giving up all hope, experiments were made artificially to increase the capacity of the ground-water stream. Unto a layer of sand, rising above the clay, where the surface of the free ground-water stood at a level with the artesian level on the bank of the river (Fig. 6), water was led for several months uninterruptedly, and, on account of the favorable results obtained from it.

a plan was made up for the production of permanent ground-water, which installation has been working since the autumn of 1898 (Figs 7—8)*.

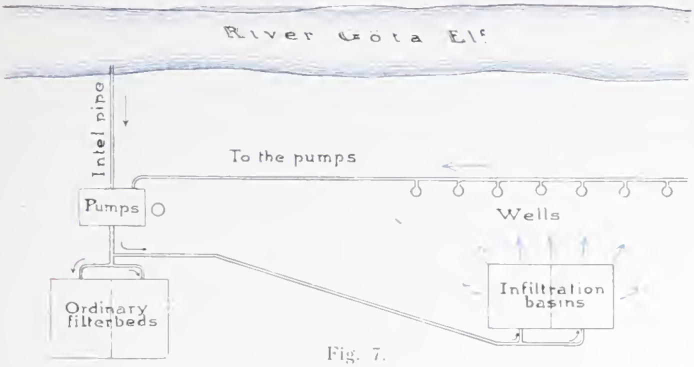

Fig. 7.

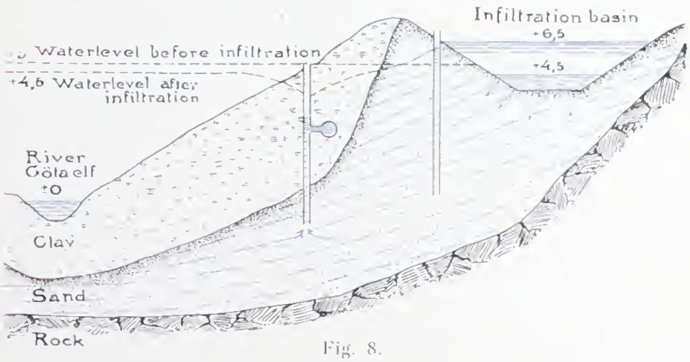

Fig. 8.

The whole surface of the infiltration-basins is about 5,000 square metres. Their bottoms are 0,5 metre under the surface of the natural ground-water or + 4,5 (Fig. 6), and the water-surface stands at + 6,5 in free connection

* The drawings are exhibited in Paris. Section for Hygiene.

with the older filter-basins at the pumping-station. At 200 metres below the basins the ground-water is collected in 20 wells and runs off by gravitation to a pump-well near the engine-house. The ground-water level is, on an average, + 3,5 between the wells, and in an observation-well sunk near the pumping-house + 4,5; the natural water-level below the complex of wells has, therefore, been sunk 0,5 metre or 10 per cent.

As the supply of natural ground-water, 2,000 cubic metres in 24 hours, corresponds with a pressure of 5 metres, the 10 per cent decrease of pressure represents a decrease of only 200 cubic metres, which may be totally disregarded. Every drop of the infiltered water thus goes to the wells.

The difference of height between the water-levels in the basins and in the underground, at the beginning of the filter-period, reaches 0,15 metre and is afterwards increased in the course of 2—3 months to 0,7—1,0 metre, after which the basins are closed, emptied, and cleaned. The present capacity of the wells is only 6,500 cubic metres, representing a rate of infiltration af 1,3 metre. In order to be able to get the 11,500 cubic metres required in future, either new wells must be sunk, or the capacity of those now existing must be increased by sinking the level of the water still lower, by which the gravitation-conduit is changed to a suction-pipe.

In a qualitative respect the results have been fully satisfactory. The water is clear as crystal and as good in taste as the best natural spring-water. The quantity of chlorine, which in the middle of the natural stream amounts

to 200 lmg, is in the wells only 90 lmg, and the amount of ammonia has never exceeded 0,6 lmg. The temperature varies between + 8° C. in summer and + 10° C. in winter, and the amount of bacteria, in about half of more than 100 samples, has been = 0, which proves that the water is completely sterile.

The natural filtration has thus been sufficient, in this case, to change the frequently impure and slimy river-water into a spring-water of the best quality. The artificial ground-water is even better than the natural water, as it contains much less chlorine and ammonia. The reason of this is, probably, that the artificial stream between the basins and the wells has relatively but a short time been in contact with the deposits in the filter-bed.

Even if this establishment which, in certain respects, is the first of its kind, suffers from several imperfections, it has nevertheless proved the possibility to purify and improve river-water by artificial ground-water production much better and more cheaply than with the aid of usual filtering.

It is my conviction, that the artificial ground-water production can be used to great advantage at several water-works, and I take the liberty of giving a few examples.

The new water-works of *Stockholm* are to be placed a few kilometres west of the town, on the shore of Lake Mälaren on an "ås" which, towards the north, continues over Ecker Isle and the opposite shore of the Mälaren. South of the Mälaren and a few metres higher, there is the deep and clear Bornsjön (Fig. 9).

The intention is, first to use the ground-water supply

Fig. 9.

of the "ås", then filtered water from Bornsjön, and in the last instance water from the Mälaren which, at certain times, is grayish and difficult to purify by usual filtration. "Åsar", which are only found in Scandinavia and other formerly ice-covered countries, are gravel deposits from glacier-rivers, in tunnels under the ice, and have thus got the characteristic form of ridges. They consist usually, at the top, of fine sand and, under it, of coarse gravel and cobbles and are bedded in sand and layers of clay from the later submergence of the country in the sea. The "ås" in question has, however, a rain-water territory that is much too small to supply more than a fraction of the calculated quantity of water, and the same

is the case with Bornsjön, for which reason the greater part must be taken from the Mälaren.

In this case it seems to me most suitable to sink the level of the ground-water of the "ås" by wells on the shore of the Mälaren below the surface of the said lake, when the natural filtration will soon cease in consequence of the deposit of slime at the bottom of the lake, and then increase, as required, the supply of ground-water by artificial filtration, first from Bornsjön and then from the Mälaren. If the level of the ground-water can be sunk deep enough, it is not impossible, that the water from the Mälaren can be led in by gravitation into the »ås» on the side of Ecker Isle, and the wells will thus receive influx from both sides, whereby the capacity of the filter-bed will, of course, greatly be increased.

Helsingfors is supplied with filtered water from Vanda River which, at times, is coloured a disgusting brown and much sullied. To the west of the water-works the brook is cut by an »ås» (Fig. 10). If the water of the brook was led into that "ås" at *a* and again pumped out of wells at *b*, it would probably be purified much better than it is now.

At St. Petersburg, where the water of the Neva no longer satisfies the wants of the town, hydrological investigations are being made at Dudersdorf, but the results having been anything but satisfactory, it will be necessary to make use of filtered water from Lake Ladoga. Is it, not possible in this case, to increase the capacity of the ground-water stream by artificial infiltration?

The existing water-works for the supply of *London* are no longer able to satisfy the increased wants of the

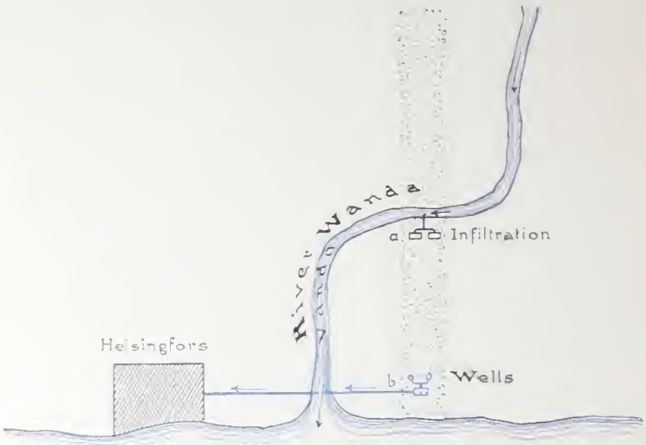

Fig. 10.

great metropolis, and thė plans for extension, which have hitherto been produced, are not satisfactory, either from an economical or technical point of view. Not even the capacity of the Thames is considered sufficient without the help of enormous reservoirs to fill the want during dry summers. The uppermost layer in the valley of the river consists partly of clay (London clay), but otherwise the ground consists of sand and below that of chalk to a depth that can amount to 300 metres, from which comes the best, but, unfortunately, the smallest part of the water-supply.

Here too, it ought not to be impossible to produce ground-water by artificial infiltration in the layer of sand, which is proved to be in direct hydraulic connection with the chalk. It can be done, for instance, by sinking wells along a collecting pipe, 20 kilometres long, and by the infiltration being divided between two systems of the

same dimensions, at 5 kilometres distance from the wells, as shown in Fig. 11.

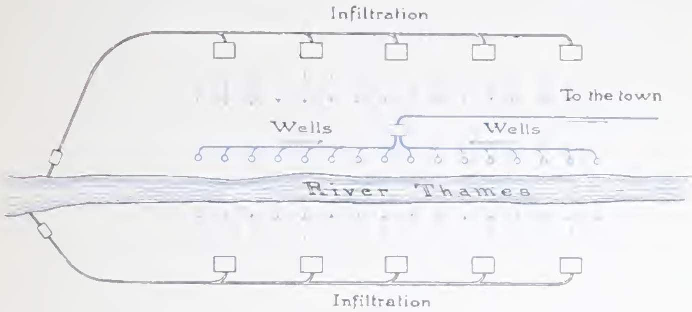

Fig. 11.

If the depth of the ground-water is taken at 100 metres and the space filled with water only at 2,5 per cent of the volume of the ground, each ground-water stream gets a free sectional area of 5,000 square metres and can, with a speed of 20 metres a day — 0,5 metre reckoned for the whole section — give *one million cubic metres* or half of the calculated want for the future. As the length of way for the water is 5,000 metres, the store of the two reservoirs between the basins and the wells cannot be changed in less than 250 days, and the variations in the quantity of infiltration are then of very little importance.

If it is not possible, out of consideration for the interests of the private companies, to carry out a plan, common for the whole city, it ought not to be difficult to increase the capacity of each system of wells by similar measures.

Amsterdam and other Dutch towns get ground-water from the downs by long collecting conduits (Fig. 12).

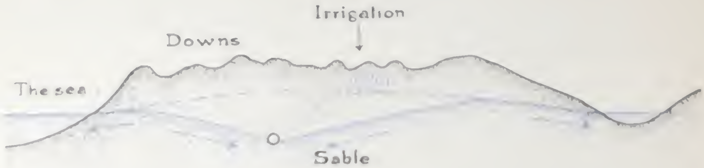

Fig. 12

The water-supply is determined by the extent of the infiltration-territory and is generally calculated to amount to 50 per cent of the rain-water. Instead of successively drawing in new infiltration-territories it would, no doubt, be possible manifoldly to increase — probably best by irrigation — the capacity of the present conduits.

A geological section from south to north through *Brussels* shows the following formations. (Fig. 13).

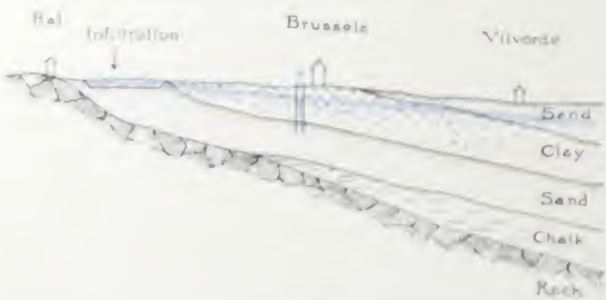

Fig. 13

Fifty years ago the wants of water of this town could be satisfied by means of artesian wells in the layer of sand, but, in consequence of many new establishments of this kind, the surface of the ground-water has been sunk, and the capacity of the wells has decreased, for

which reason a new and very expensive establishment has been built to make use of distant springs. Could not the matter have been arranged in a much more simple and cheaper manner by artificial infiltration in the surface of the sand at Hal?

At *Toulouse* they are thinking of abandoning the natural filtration and building artificial filters for the daily purification of 35,000 cubic metres of water from the Garonne (see page 6). It would be better and cheaper to pump 30,000 cubic metres into open infiltration-basins and thus increase the capacity of the ground-water stream from 10,000 to 40,000 cubic metres. If 35,000 cubic metres were collected by means of wells, 5,000 cubic metres would go to the Garonne and completely stop the stream in the contrary direction.

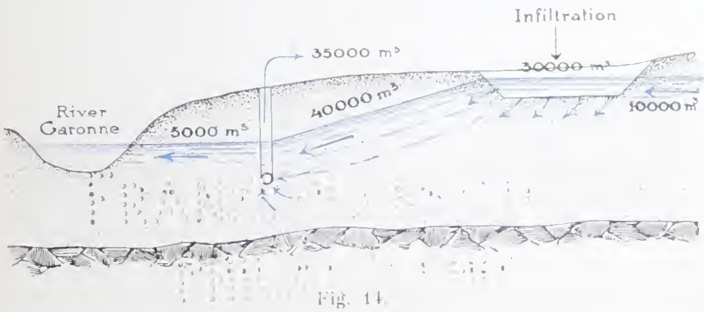

Fig. 14.

In many towns, where the natural filtration gives a bad quantitative result, the deficiency could be supplied by building cleansable infiltration-basins, to which the river-water could be led, either by pumping as in fig. 14 or by gravitation as in fig. 15.

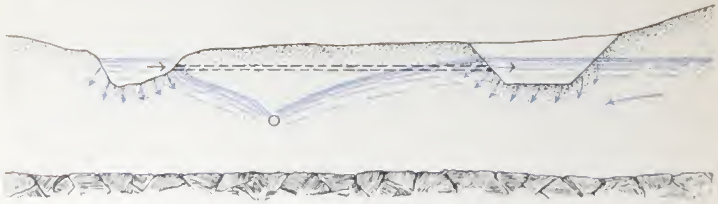

Fig 15.

In *Paris* great exertions are made in order to exchange the bad water from the Seine for ground-water and they extend the collecting of water to more distant territories of springs. But at only a short distance there are excellent valleys, full of porous sand and layers of chalk, where the ground-water streams, now insufficient, could be increased by artificial infiltration. Even on the banks of the Seine there ought to be no difficulty in applying the same method. *Belgrand*, to be sure, proved, by direct trials, the impossibility of applying the usual natural filtration,* but the matter becomes, of course, different, when cleansable infiltration-basins are used, arranged as in figs 14 or 15. The higher degree of hardness in the natural ground-water seems discouraging, but, during the relatively short filter-period of one or two months, the water of the Seine would probably not have time to undergo such a complete change.

(See the result at Göteborg, pag. 23).

The filter-works of *Berlin* are of the best that exist, but they have cost enormous sums. Now, however, they seem inclined to follow the example of the suburbs which,

* Belgrand, la Seine.

with the greatest success, have built ground-water-works If, according to future investigations, the natural ground-water should be found insufficient — of which there is little fear — the surrounding extensive sand-fields offer the very best means for infiltration of — one can well say — unlimited quantites of water from the Spree, or the Havel.

In *Vienna* they discussed, some years ago, a plan that is, for the present, abandoned, of supplementing the celebrated spring-water conduit by a ground-water stream south-east of the town, which was considered to have been formed chiefly by natural infiltration from the river Schwarza during high-water periods. Among the inconveniences of the plan were the difficulties to examine the constant capacity of a stream 10 kilometres wide, where even a very powerful and long pumping would produce an insignificant depression of the surface of the water-level.

In this case, to judge by the results obtained by the borings and the observations as to water-levels, the deep and porous gravel-beds should allow considerable quantities of water to pass. If, in spite of that, the capacity be insufficient, the indications of nature could be followed and a permanent infiltration be arranged from the river Schwarza with the assistance of cleansable basins. (Fig. 16).

For the matter of that, even at a hydrological investigation, they could here, with advantage, have made use of artificial infiltration instead of experimental pumping. The capacity of the natural ground-water stream can be calculated just as well by the elevation of the water-level, corresponding to a certain quantity of infiltration, as by

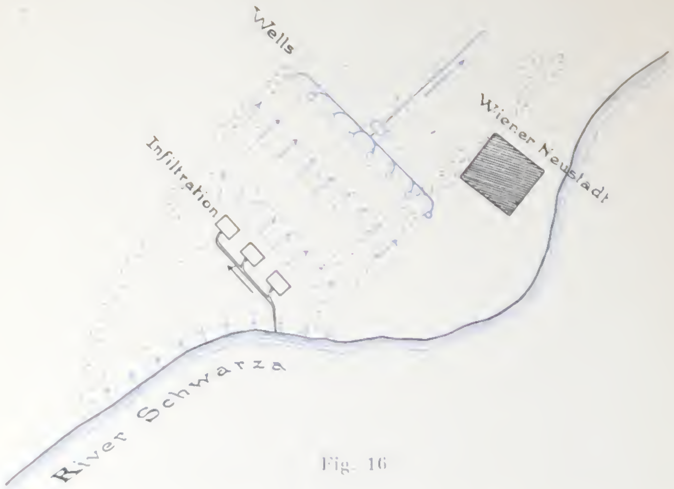

Fig. 16

the depression, produced after pumping up a certain quantity. A provisional infiltration-basin is much less expensive to build and to use than pumping for several months at the rate of one cubic metre of water a second from the provisional wells.

But the gourmets of Vienna will not permit their idolized high-spring-water to be mixed up with usual ground-water. The capacity of the springs is, unfortunately, very changeable, depending on the melting of the snow in the Alps of Steiermark. By damming up and storing the water which flows away unused during spring and autumn, and by feeding infiltration—or irrigation-basins from the reservoirs thus formed, no doubt even the alpine ground-water streams could be increased.

From the above it will be seen that the artificial production of ground-water, planned and carried out in a

rational way may, in future, play an important part in the science of sanitary engineering. Which method may be most suitable to use — *natural filtration, intermittent irrigation, or infiltration in cleansable basins* — depends in every special case on local conditions. The constructive arrangements of the establishment, and the quantitative as also the qualitative results can only be determined by careful hydrological examinations. One thing, however, can be considered as indisputable i. e. *that surface-water can be purified, by the artificial production of ground-water, incomparaply better and cheaper than with usual filters.*

Stockholm, April 1900.